Frontogenesis in a tropospheric frontal zone: a case study

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Frontogenesis defined as a process of temperature horizontal gradient change in the air particle represents one of main mechanisms for properties redistribution between different scales of motion. Frontogenesis plays an important role in forcing vertical circulations. In the ascending branches of the circulation cells, at the atmospheric surface fronts, clouds and precipitation develop. In the upper and middle troposphere and in the jet stream layers, the descending branches generate stratospheric intrusions – areas of stratospheric and sub-stratospheric air sinking to the tropospheric levels.

In the paper, a case of upper-level frontogenesis over Russia is analyzed on the real (objective analysis) data. For this purpose, two components – Q_n and Q_s - of the vector frontogenetical function $\boldsymbol{Q}$ are calculated, the s and n axes being directed along and across the isentrope (the potential temperature, θ, contour):

$$\begin{aligned} Q_n &= \frac{1}{2}|\nabla\theta|\left[D - E_{sh}\sin 2\alpha - E_{st}\cos 2\alpha\right], \\ Q_s &= \frac{1}{2}|\nabla\theta|\left[\zeta - E_{st}\sin 2\alpha + E_{sh}\cos 2\alpha\right] \end{aligned} \qquad (1)$$

In (1), D is the velocity divergence at the H level, E_{st} and E_{sh} are the stretch and shear deformations, respectively, ζ is the relative vorticity, α is the angle between the x axis (directed eastward) and $\nabla\theta$.

Q_n is frontogenetical component or scalar frontogenesis function, and Q_s is rotational component (Keyser *et a*l., 1988). Also, the right-hand side of the ω-equation

$$N^2\nabla_p^2\omega + f^2\frac{\partial^2\omega}{\partial p^2} = -2\nabla_p\cdot\vec{Q}. \qquad (2)$$

is considered. In (2), N is the Brunt-Vaisala frequency, $\omega = dp/dt$ is the vertical velocity, p is the pressure, f is the Coriolis parameter, the ∇_p operator is related to the isobaric surface.

The calculations are carried out on the objective analysis data with horizontal resolution of 1.25^o both in latitude and longitude for the period of December 11 to 15, 2013, when over European Russia a warm front was situated associated with a deep low centered in Scandinavia. The tropospheric frontal zone over and ahead the front surrounded a deep, narrow trough whose axis was oriented from NE to SW. The situation has much in common with the conceptual model by Shapiro (1081) at the stage when a closed low develops in a deep trough. At the NE branch of the frontal zone, a strong jet stream exists with a jet streak, at the entrance of which, a deep stratospheric intrusion (streamer) develops at its cold side.

The calculated rotational component, Q_s, is found to force a band of intense descending motions inside the streamer (Fig.1). Along its axis, a chain of deep minima of tropopause height (maxima of pressure at the 4 *pvu* surface) are obtained. Physical consistence of these minima is questionable because of restricted horizontal resolution of the data under use. On the other hand, the findings by Appenzeller *et al* (1996) have proven that the real stratospheric intrusions are subject to fragmentation into chains of smaller funnels and eddies, similar to some extent to those shown in Fig. 1, b.

The frontogenetical component, Q_n, at the cold side of the fontal zone and jet stream gives rise to strong descending motions and contributes the stratospheric intrusion deepening, while at the warm side, it forces intense ascending in the 500-250 hPa layer, as a result of isotherm turning in the south part of the tropospheric trough (Fig. 2).

Thus, both scalar and rotational components of the vector frontogenetical function force, in the situation under consideration, thermally direct circulations. The maxima of both components are of the same order of magnitude, but they act in different parts of the field. In accordance with the Shapiro conceptual model, at the approximately linear part of the frontal zone, the scalar frontogenesis plays the primary role in the stratospheric intrusion development, while in the zone of the streamlines maximum curvature, such role is played by the rotational frontogenesis.

References

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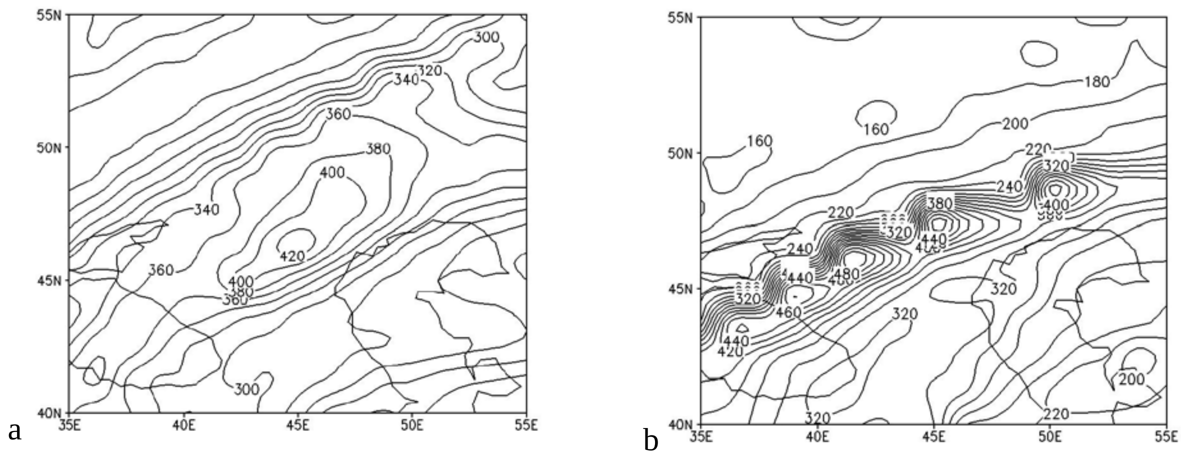

Fig. 1. Tropopause height (pressure, hPa, at the 4 *pvu* surface) at 00 (a) and 12 (b) UTC, December 12, 2013.

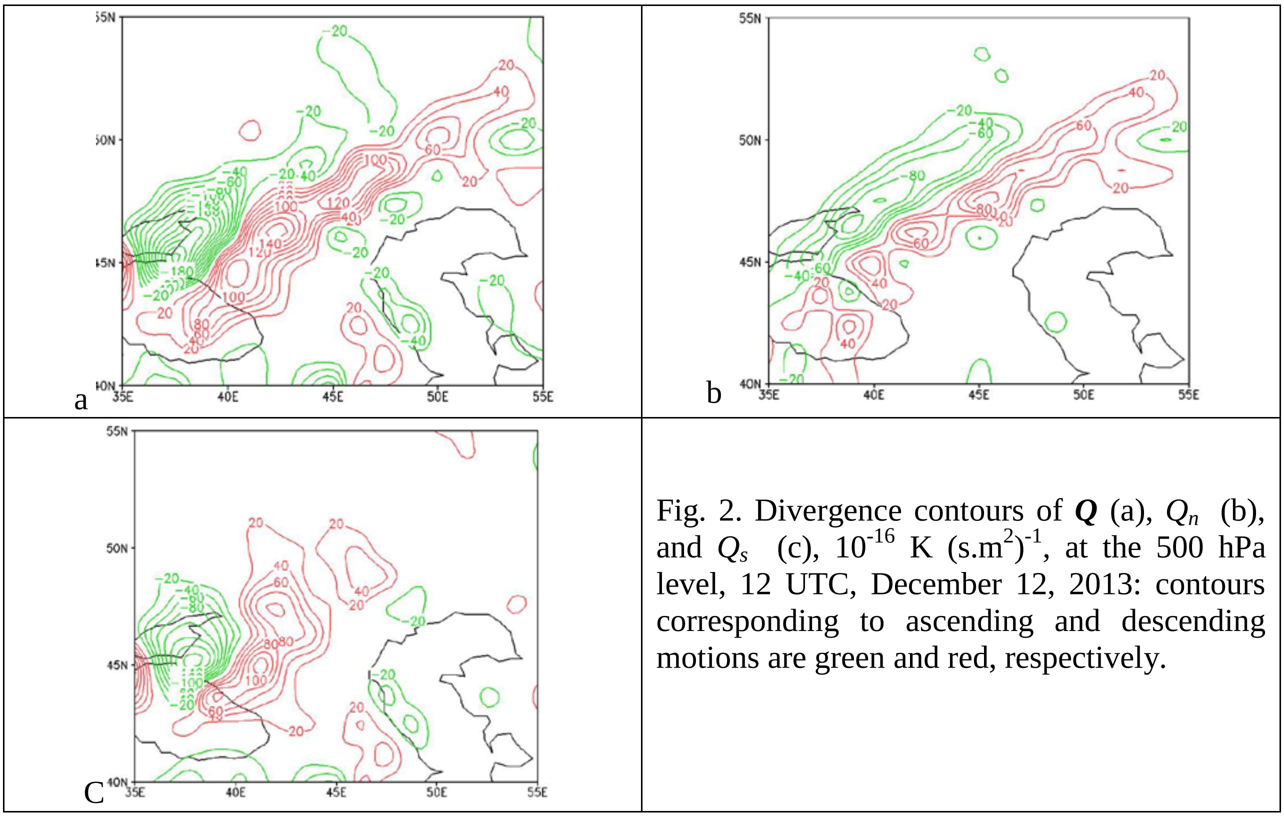

Fig. 2. Divergence contours of $\boldsymbol{Q}$ (a), Q_n (b), and Q_s (c), 10^{-16} K $(s.m^2)^{-1}$, at the 500 hPa level, 12 UTC, December 12, 2013: contours corresponding to ascending and descending motions are green and red, respectively.